Recent Developments in Damping Rings and their Wigglers

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CARE05 - ELAN

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Outline

- General considerations on Damping Ring (DR) wigglers
- The ILC DR
- Wigglers for ILC DR
- The CLIC DR
- Wigglers for CLIC DR

Damping time and Emittance

- Increasing $\int B^2 ds$ wigglers allows to achieve the short damping times and ultra-low beam emittance needed in Collider Damping Rings
- A good wiggler design is one of the key points for the Damping Rings operation

Damping time and normalized emittance

$\tau = 2T_0E/U_{0}$; $U_0 \propto E^2 \int B^2\, dl$

$U_0 = U_a + U_w$; $F_w = U_w/U_a$

$\varepsilon_a \propto E^3$ flat θ_{bend}^3; $\varepsilon_w \propto B_{wig}^3\, \lambda^2 \langle\beta\rangle$

$\varepsilon_x = \varepsilon_a/(1+F_w) + \varepsilon_w F_w/(1+F_w) \approx \varepsilon_a/F_w$; $F_w \gg 1$

$$\tau \propto T_0/(E \int B^2 ds) \; ; \quad \varepsilon \propto E/\int B^2 ds$$

Increasing $\int B^2 ds$ wigglers allows to reduce both damping times and beam emittance at the same time

Radiated energy needed to get a given Damping time

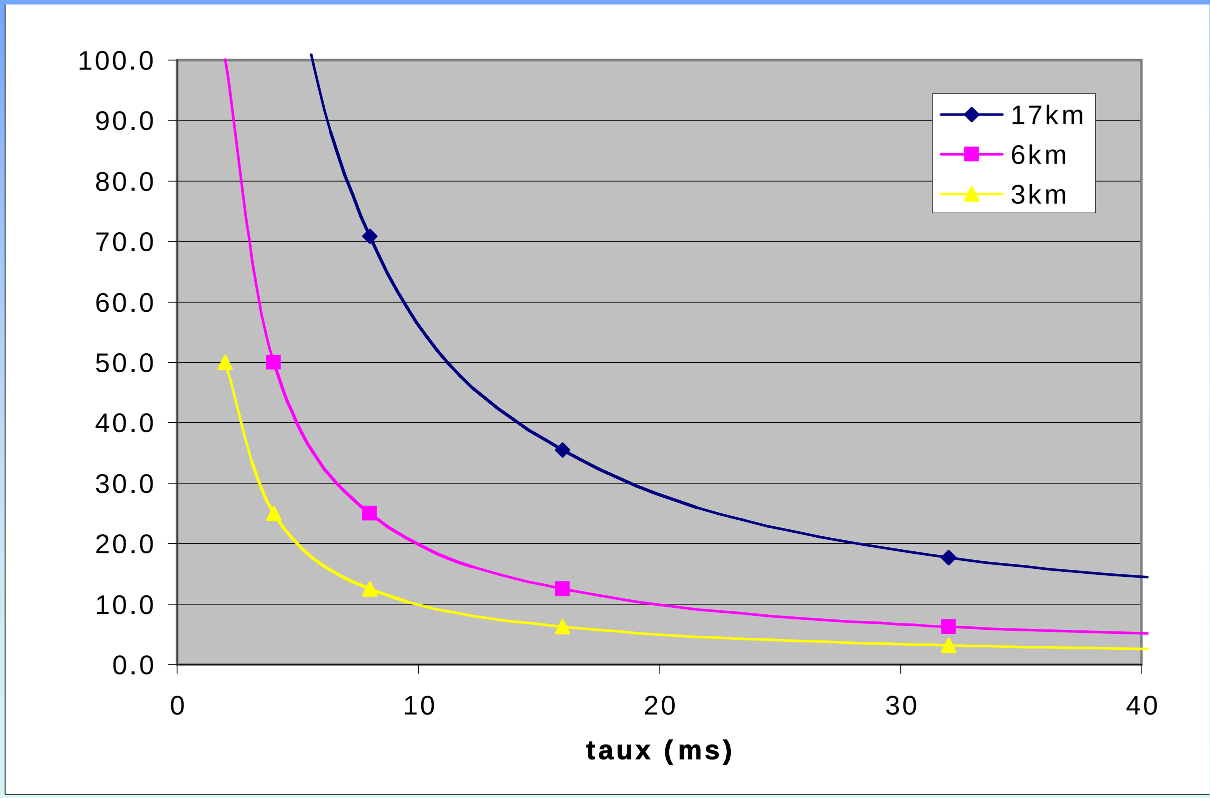
$\tau = 2T_0E/\,U_0$

$U_0 = C_q/2\pi\; E^4 \int 1/\rho^2\, dl$

$C_q = 88.5e\text{-}5$ Gev-3m

$U_0 \propto E^2 \int B^2\, dl$

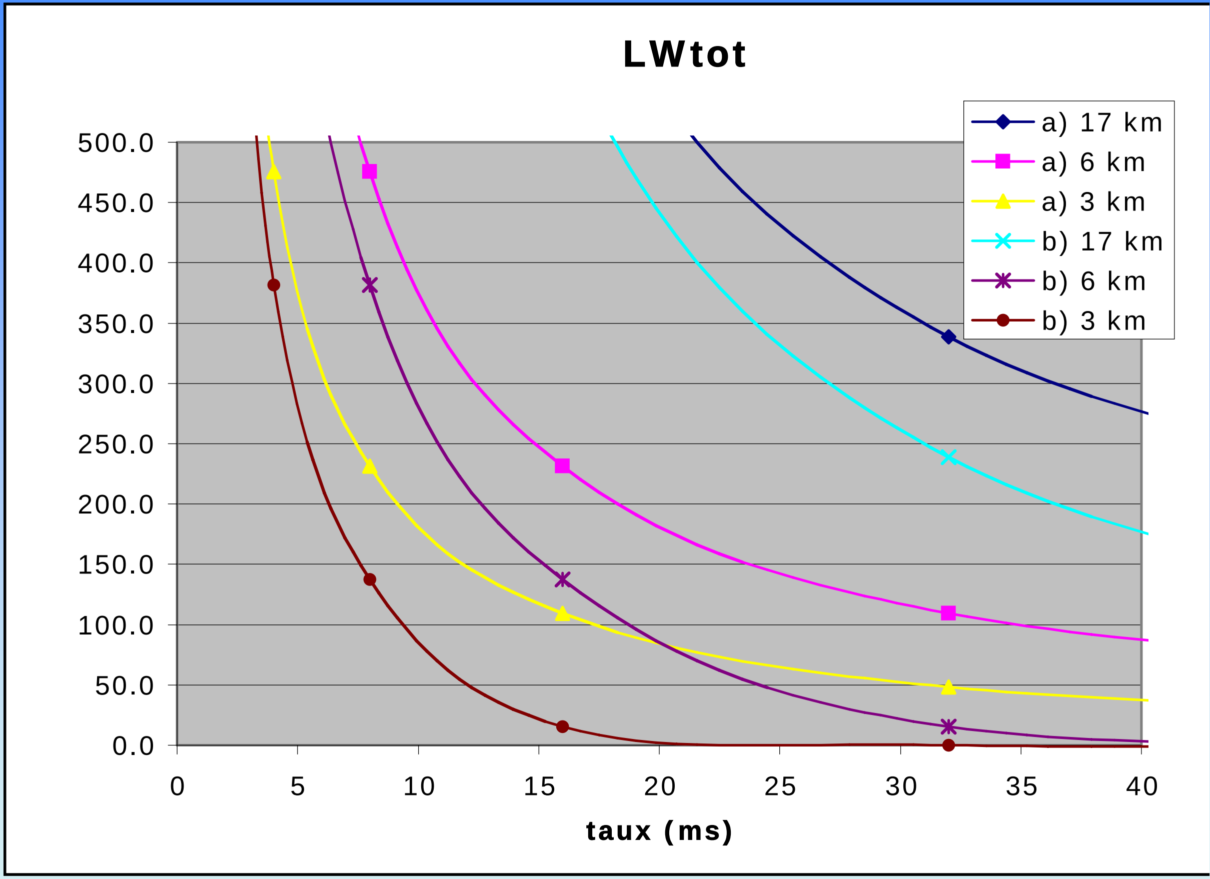
$\tau \propto T_0/(E \int B^2\, dl)$



U_0 (MeV)

	τ=28 ms	τ=14 ms
17 km	20.3	40.5
6 km	7.1	14.3
3 km	3.6	7.1

Wiggler length needed to get a given Damping time



L_W (m) - B_{arc} = 0.2

	τ=28 ms	τ=14 ms
17 km	388	783
6 km	127	266
3 km	57	127

L_W (m) - B_{arc} = B_{wig}

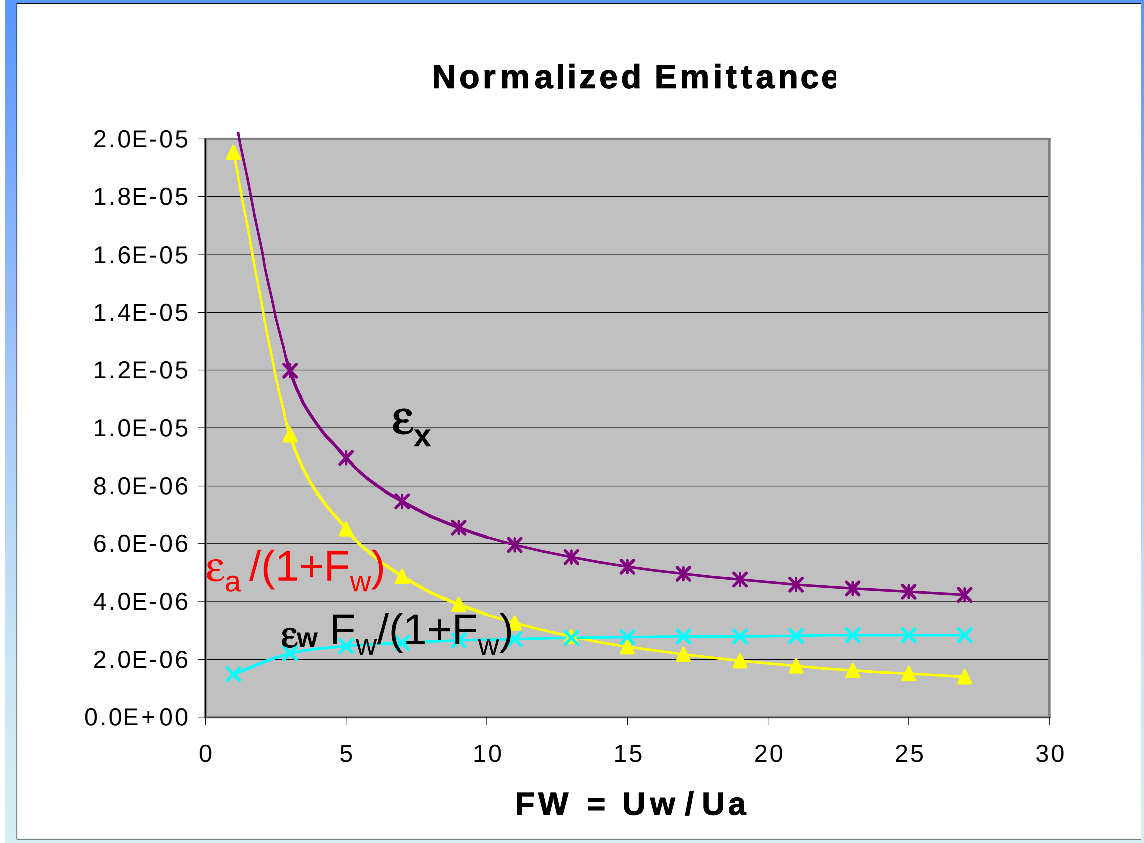
	τ=28 ms	τ=14 ms
17 km	288	684
6 km	32.8	172
3 km	0	32.8

a) B_{arc} = 0.2 T => low field to reduce emittance

b) B_{arc} = B_{wig} = 1.65T (100 m shorter wiggler)

Normalized Emittance

$$\varepsilon_x = \varepsilon_a/(1+F_w) + \varepsilon_w F_w/(1+F_w)$$



$\varepsilon_a \propto E^3$ flat θ_{bend}^3

$\varepsilon_w \propto B_{wig}^3 \lambda^2 <\beta>$

$F_w = U_w/U_a$

F_w	13
τ_x (ms)	22
ε_a (m)	3.9e05
$\varepsilon_a/(1+F_w)$ (m)	2.8e06
$\varepsilon_w F_w/(1+F_w)$ (m)	2.7e-6
ε_x (m)	5.5e-6

Wiggler Parameters

$\varepsilon_w \propto B_{wig}^3 \lambda^2 <\beta>$

There are three possibilities to reduce the wiggler emittance:

a) Long wiggler with relatively low field

- this gives a smaller rms relative energy spread σ_p, which is one of the requirements for a DR.
- The SR power emitted per unit length is also reduced making easier the vacuum system and SR absorbers.

b) Short period

- Low field and small gap or
- SC magnet

Wiggler Parameters

c) Small average beta

- A wiggler section is made of n cells each with a wiggler magnet with one (or more) quadrupole at each end.
- To reduce the $<\beta>$ one can:

  - increase the strength of the quadrupoles (increasing chromaticity)

  - reduce the wiggler length (increasing cost).

Effect of wiggler nonlinearities on DA

- octupole terms produce a tune shift on amplitude which reduces the Dynamic Aperture
- **Intrinsic octupole term** in the vertical plane for an **ideal wiggler** (infinite pole width)

$$\Delta\nu_y/J_y = \pi L_w \langle\beta_y\rangle^2/(\lambda_w^2\rho_w^2)$$

- Cures:
  - Reduce the effect on the beam reducing $\langle\beta\rangle$
  - Insert octupoles in the ring to compensate the effect on the beam

Effect of wiggler nonlinearities on DA

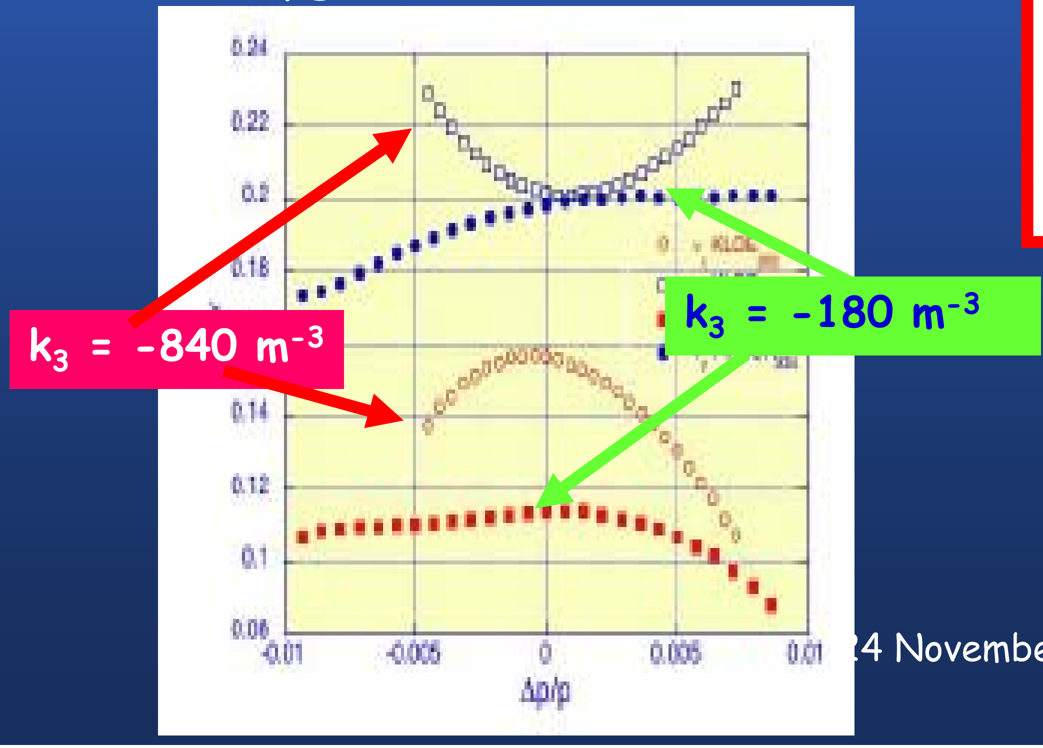
- An **octupole term** comes from the combination of the oscillating trajectory with the decapole term due to the finite pole width.
- Cures:
  - Increase pole width
  - Shimming of the pole shape (DAFNE wigglers, TESLA optimized)
  - Reduce the effect on the beam reducing $<\beta>$
  - Insert octupoles in the ring to compensate the effect on the beam

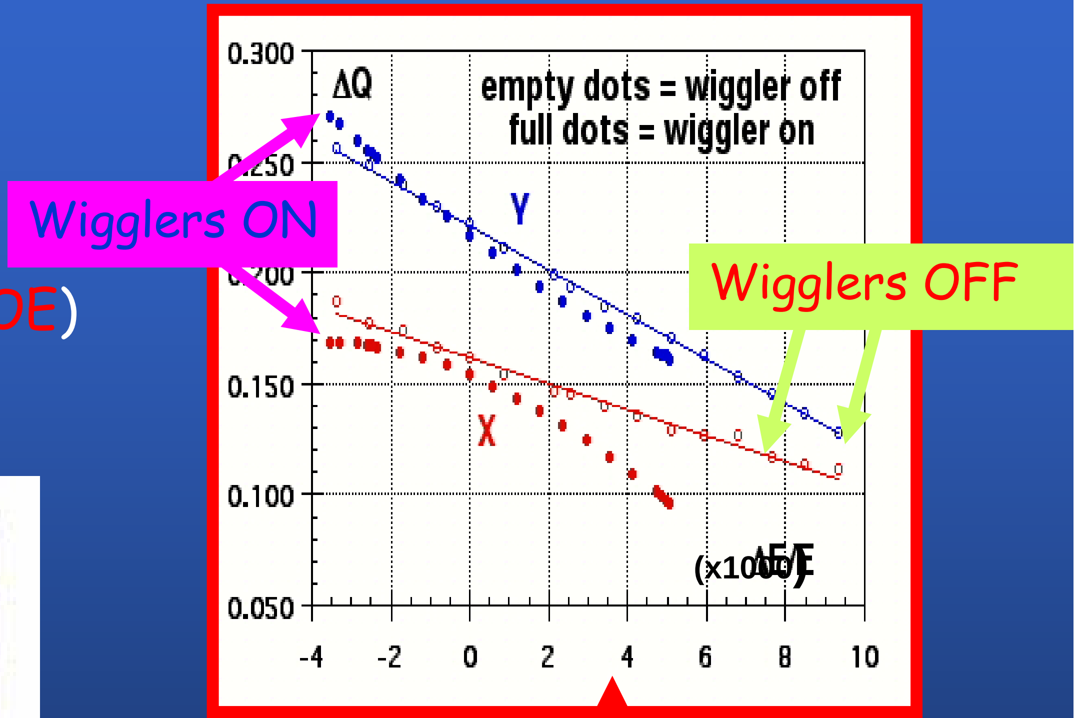
Measurements on DAΦNE wigglers (M. E. Biagini)

Tune shift vs energy with sextupoles OFF, wigglers ON & OFF

AFTER

Tune shift vs energy before (KLOE) and after (FINUDA) wigglers upgrade (2003)





BEFORE

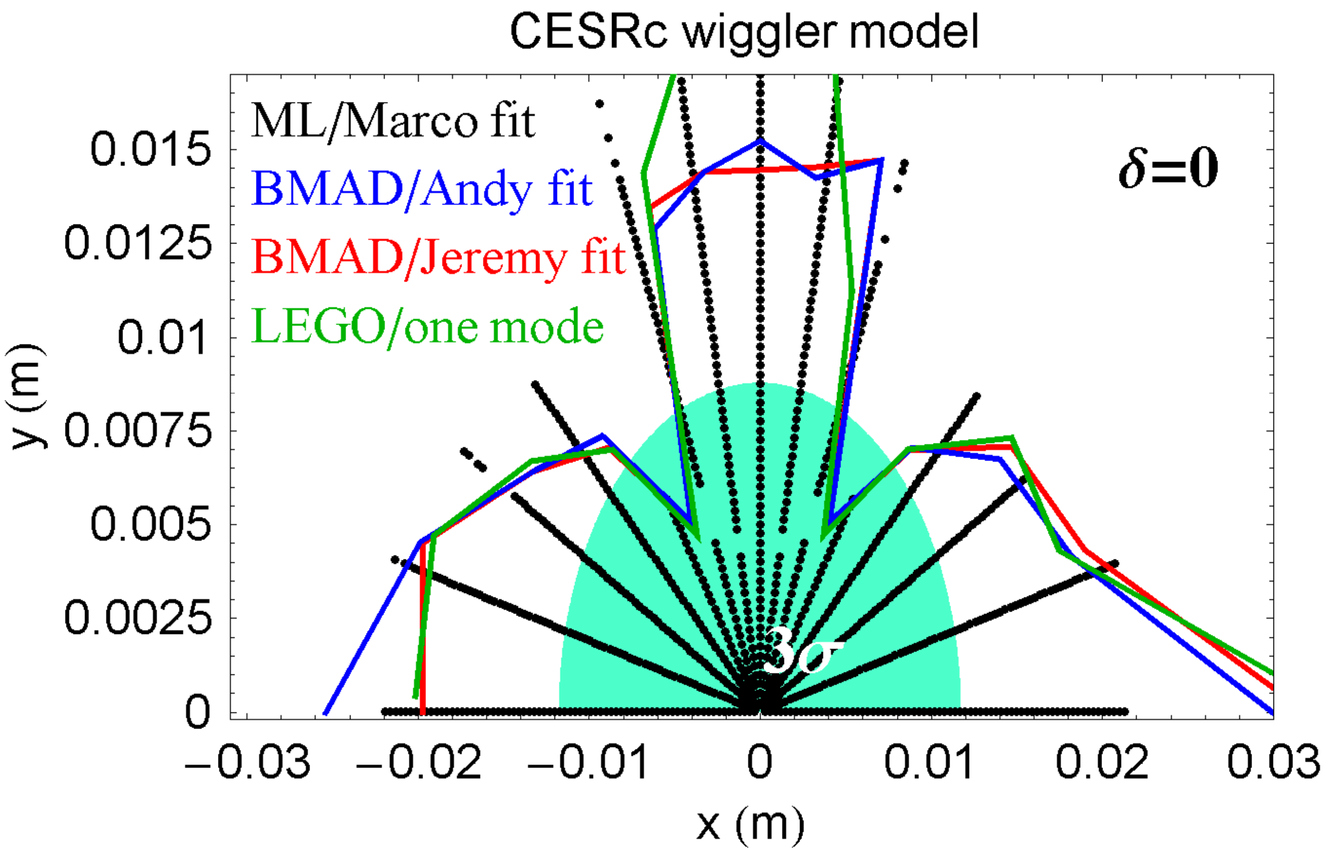
Why bothering with this exercise?

Damping rings rely heavily on wiggler insertions

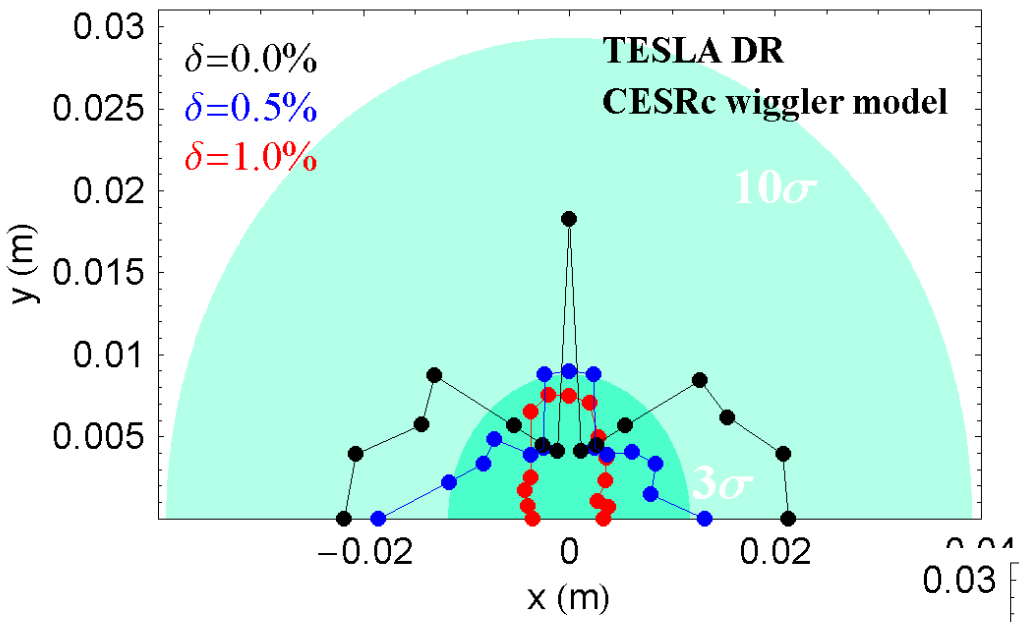
- A number of different methods/tools are being used for
  - **modeling** wiggler fields,
  - solving the equations of motion, find **transfer map**
  - doing **tracking**.
- Make sure different people using different tools get (reasonably) consistent results.
- Compare:
  - **Dynamic aperture** for TESLA DR (with scaled-down CESRc wiggler model or one-mode wiggler model)
  - **Taylor maps** for the wiggler insertion (if available)

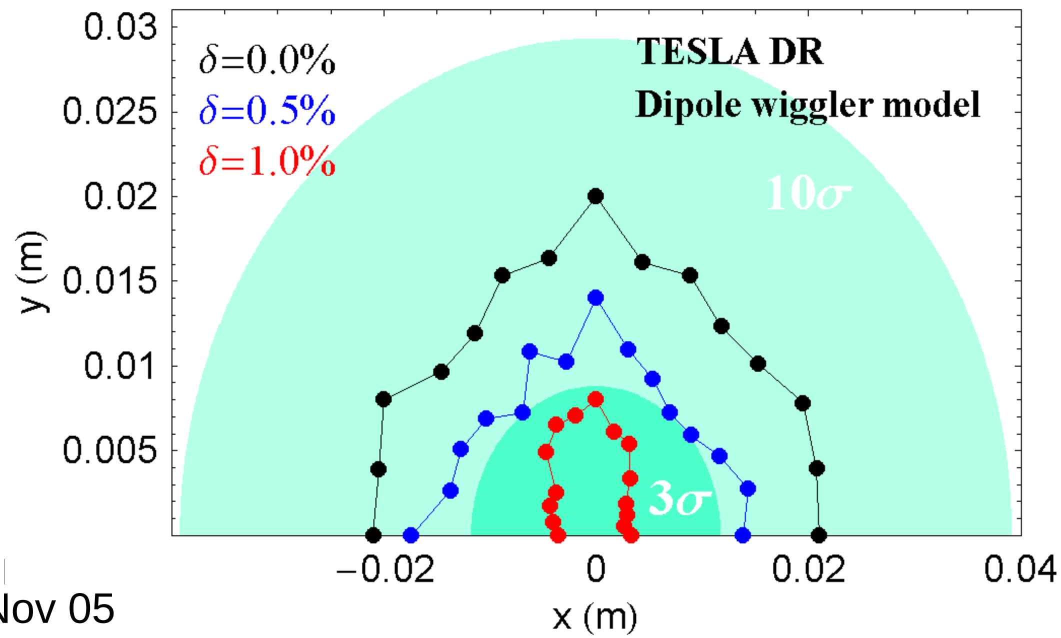
A closer look shows better agreement …

DA for TESLA DR with CESRc or one-mode wiggler model



CESRc *vs.* purely linear w-model





Tracking done by ML

Synchrotron Radiation Heating

- MW of synchrotron radiation power must be absorbed

  ILC (OCS): 4.6 MW; 28 kW/m

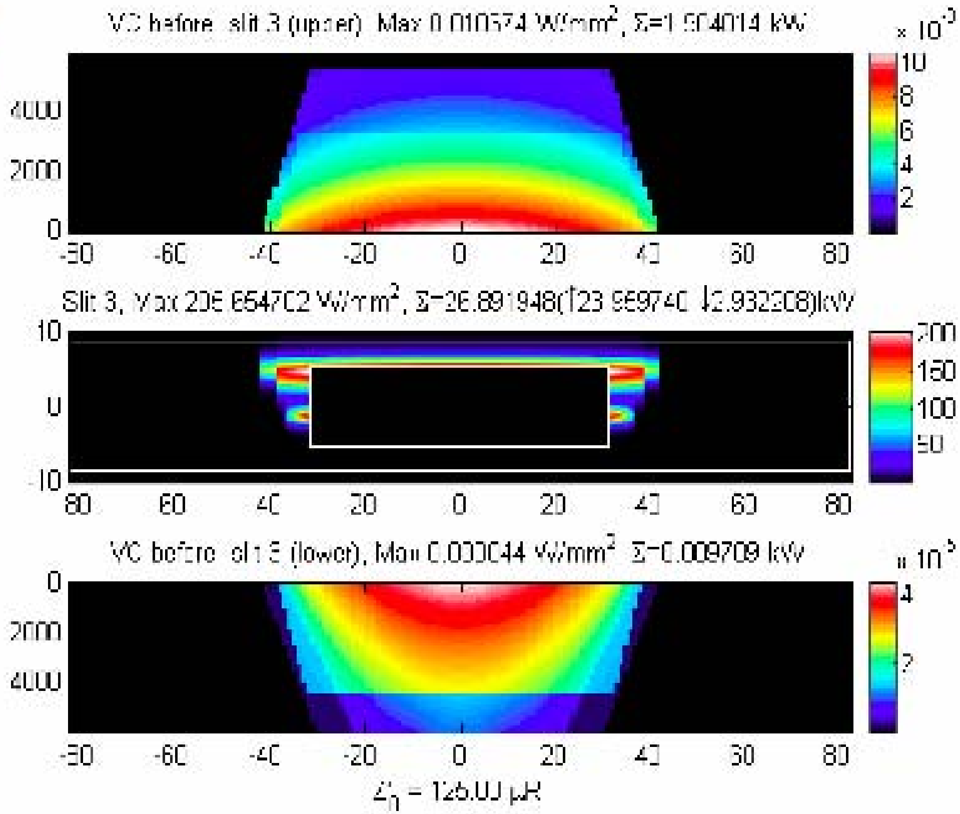
- Periodic structure of absorbers + long lumped absorber at the end of wiggler straight section
- Advantage of ILC (OCS) lattice: wigglers are distributed in 8 straight sections

Radiation heating problem

10 damping wigglers of PETRA III generate 400 kW of SR.

Periodic absorbers: 200 kW

Single 10-m absorber: 200 kW



ILC DR Baseline Configuration

- Circumference choice: 7 different lattices for the different circumferences (17 km dogbone shape, 6 km, 3 km) and layout have been analized in detail considering all the limiting effects

- Recommendation
  - Positrons: **two** (roughly circular) rings of **~ 6 km** circumference in a single tunnel
  - Electrons: **one** 6 km ring

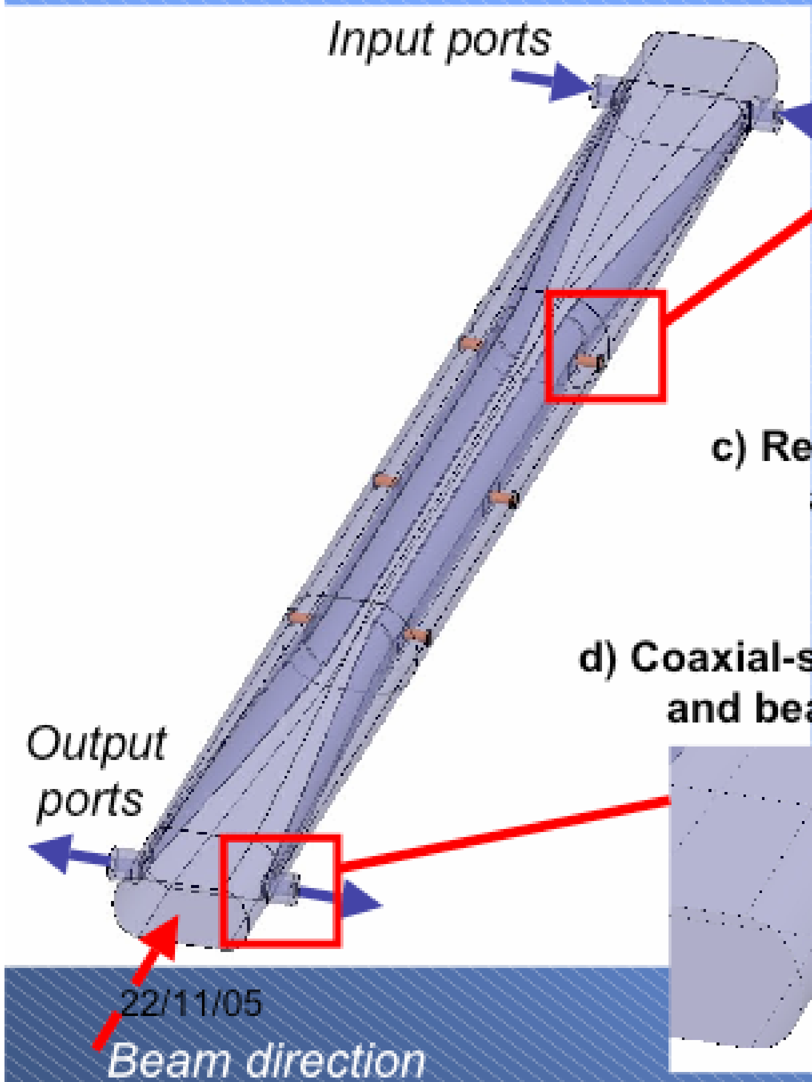
ILC DR Parameters

Energy (GeV)	5
Circumference (m)	6114
Bunch number	2820
N particles/bunch	$2x10^{-10}$
Damping time (ms)	22
Emittance $\gamma\varepsilon_x$ (nm)	5600
Emittance $\gamma\varepsilon_x$ (nm)	20
Momentum compaction	$1.62x10^{-4}$
Energy loss/turn (MeV)	9.3
Energy spread	$1.29x10^{-3}$
Bunch length (mm)	6.0
RF Voltage (MV)	19.3
RF frequency (MHz)	650

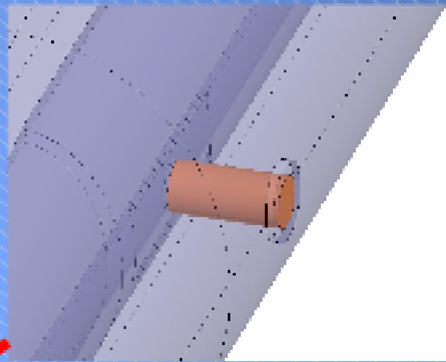
Issues for the circumference choice

- Acceptance
  - achieving a large acceptance is easier in a circular 6 km ring than in a dogbone ring.
- Collective effects
  - Electron-cloud effects make a single 6 km ring unattractive, unless significant progress can be made with mitigation techniques.
  - Space-charge effects will be less problematic in a 6 km than in a 17 km ring
  - The electron ring can consist of a single 6 km ring, assuming that the fill pattern allows a sufficient gap for clearing ions.
- Kickers
  - The injection/extraction kickers are more difficult in a shorter ring. R&D programs are proceeding fast and, it is expected that will demonstrate a solution for a 6 km circumference.

3) DAΦNE stripline kickers design: 3D electromagnetic model (1/3)



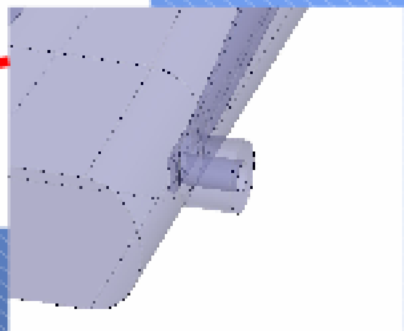
a) Ceramic stand-off effects



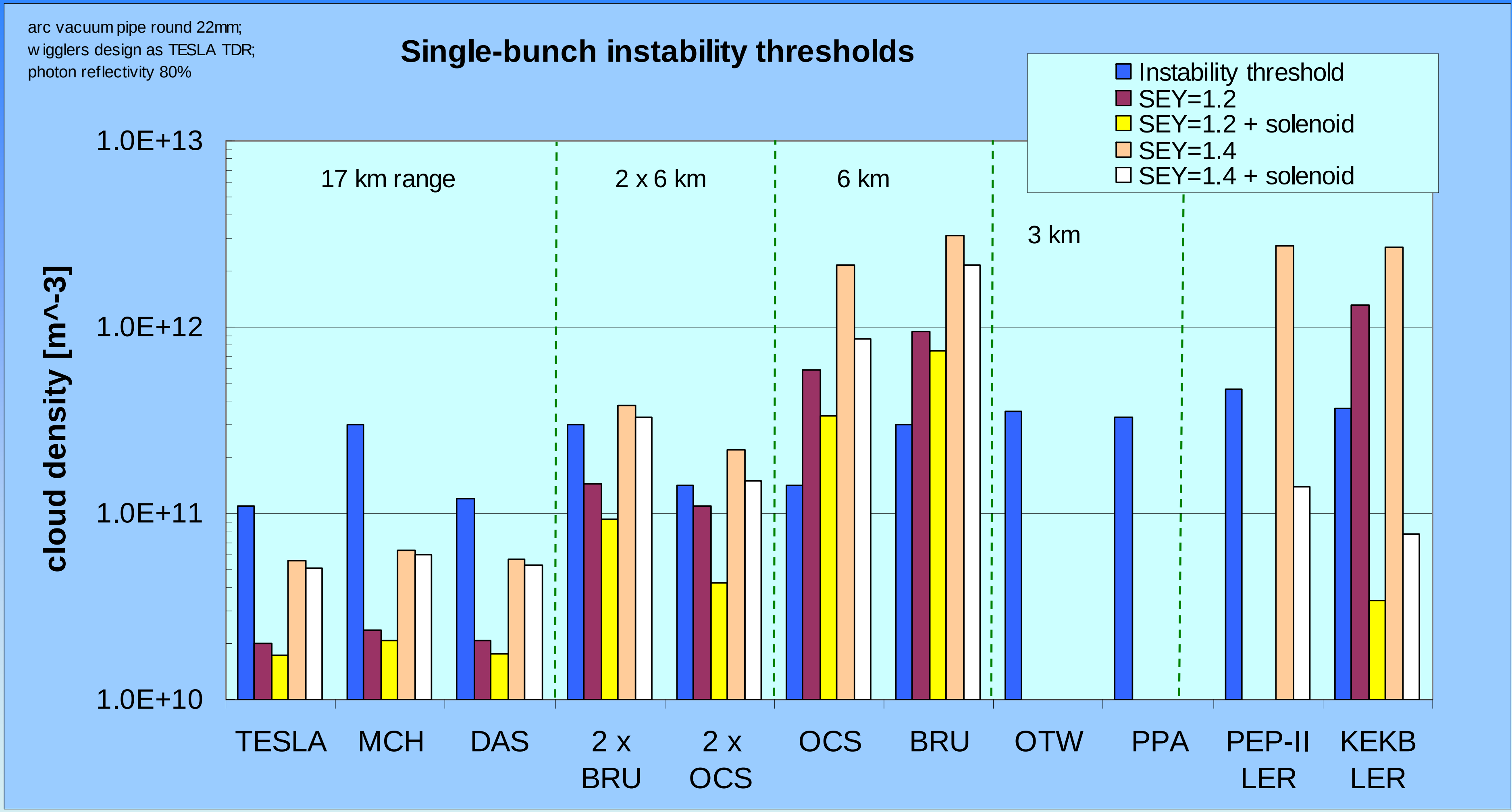
b) HOM studies

c) Real deflecting field calculation and frequency response

d) Coaxial-strip transition optimization and beam transfer impedance



Optimization of the whole structure



Single bunch instability threshold and simulated electron cloud build-up density values for a peak SEY=1.2 and 1.4.

Wigglers for ILCDR

- B_{peak} 1.6 T
- λ_w 0.4 m
- Total length 165 m
- Radiated energy 9.3 MeV

Wigglers Field Quality and Physical Aperture

- **A high quality field** is needed to achieve the dynamic aperture necessary for good injection efficiency:
- increasing the gap between the poles,
- increasing the period,
- increasing the pole
- **Physical aperture** A large gap is needed to achieve the necessary acceptance for the large injected positron beam:
  - a full aperture of **at least 32 mm** is highly desirable **for injection efficiency**
  - a full aperture of **at least 46 mm** is highly desirable **to mitigate e-cloud effects**

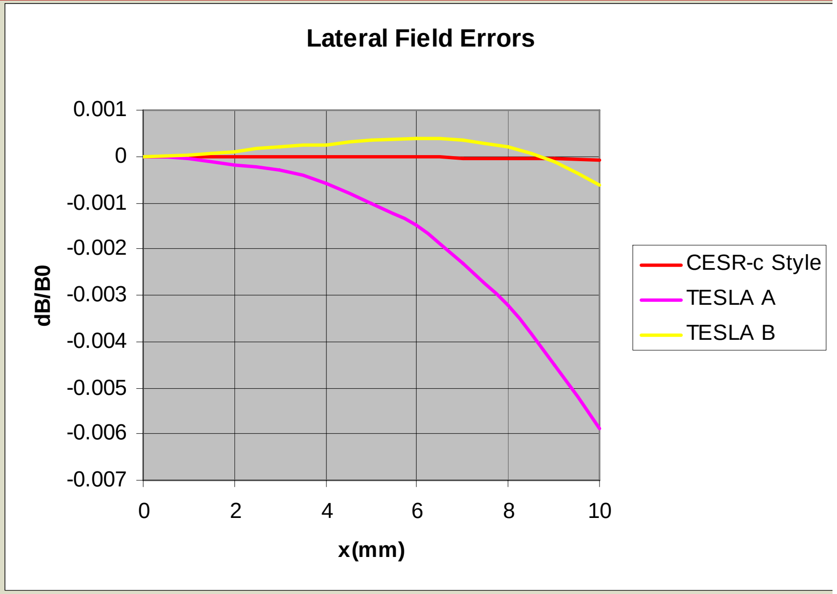
Technology Options

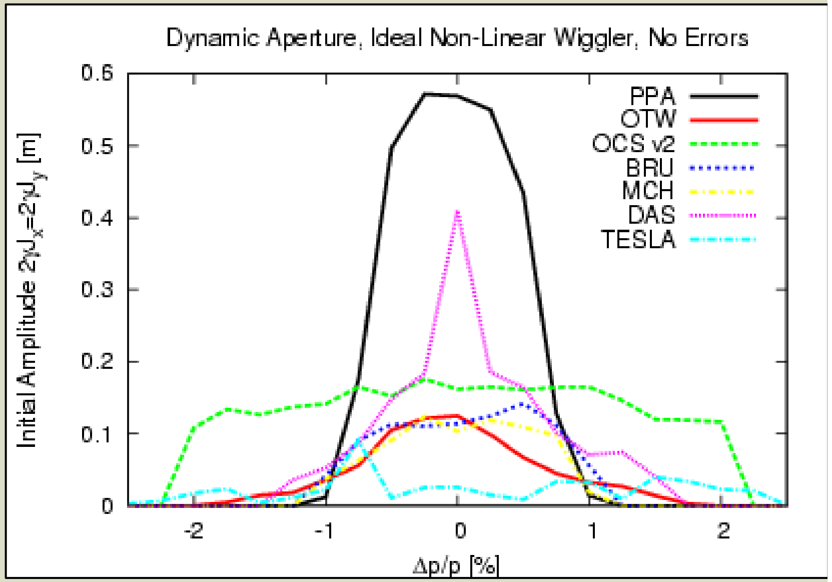
- Field requirements have led to 3 suggested options:
  - Hybrid Permanent Magnet Wiggler
  - Superferric Wiggler
  - Normal Conducting Wiggler
- Design Status
  - Hybrid PM based on modified TESLA design
    - Basic modified TESLA design (Tischer, *etal*, TESLA 2000-20)
      - 6 cm wide poles
      - Tracking simulations in hand
    - Next generation design (see note from Babayan, *etal*)
      - New shimming design
      - Improved field quality – field maps available at end of last week
      - Field fitting now underway, but no tracking studies yet
  - Superferric design based on CESR-c wiggler (Rice, *etal*, PAC03, TOAB007)
    - Tracking simulations in hand
  - No active design for normal conducting option
    - Will scale from TESLA (TESLA TDR) and NLC (Corlett, *etal*, LCC-0031) proposed designs

Field Quality

Cornell University Laboratory for Elementary-Particle Physics

- Significance: A
- Primary Issue is Dynamic Aperture
- 3 pole designs in hand:
  - Superferric with
    $\Delta B/B \sim 7.7 \times 10^{-5}$ @ $\Delta x = 10$ mm (CESR-c)
    - Shows acceptable dynamic aperture!
    - However, most designs approaching DA limit for $\Delta p/p=1\%$!
  - Modified TESLA design (60 mm pole width)
    $\Delta B/B \sim 5.9 \times 10^{-3}$ @ $\Delta x = 10$ mm (TESLA A)
    - Dynamic aperture unacceptable!
    - Note that normal conducting designs (as is) are in this ballpark
  - Shimmed TESLA design (60 mm pole width)
    $\Delta B/B \sim 5.5 \times 10^{-4}$ @ $\Delta x = 10$ mm (TESLA B)
    - Detailed field map has just become available
    - Field fits and tracking studies not yet available
    - Concerned about potential impact on DA near $\Delta p/p = 1\%$

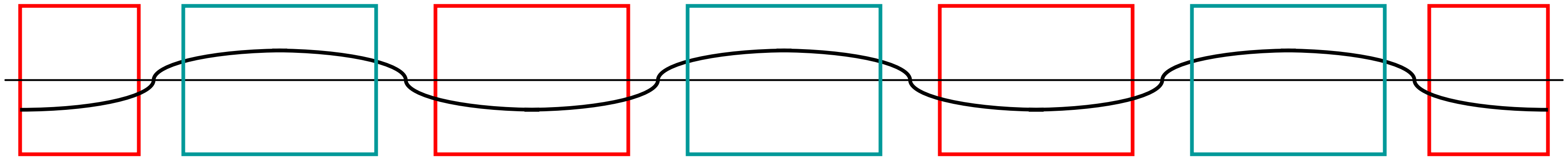




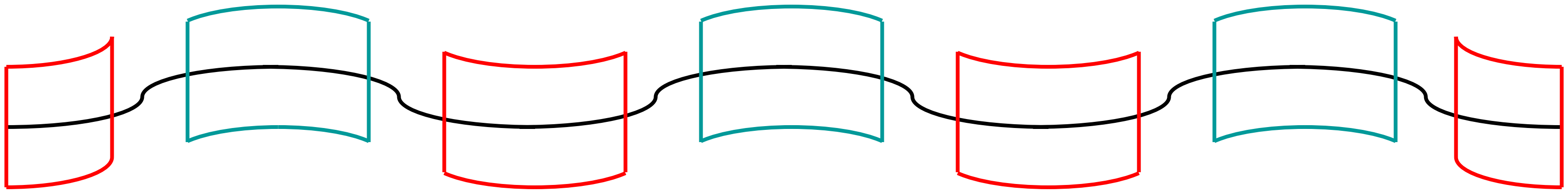
ILC DR Wiggler Technology

- **Baseline**
- The CESR-c wigglers have demonstrated the basic requirements for the ILC damping ring wigglers. Designs for a superconducting wiggler for the damping rings need to be optimized.
- **Alternatives**
- Designs with acceptable costs for normal-conducting (including power consumption) and hybrid wigglers need to be developed, that meet specifications for aperture and field quality.

Increasing the gap and pole width can increase the cost of the wiggler. An alternative solution is that of modifyng the pole shape to follow the trajectory.

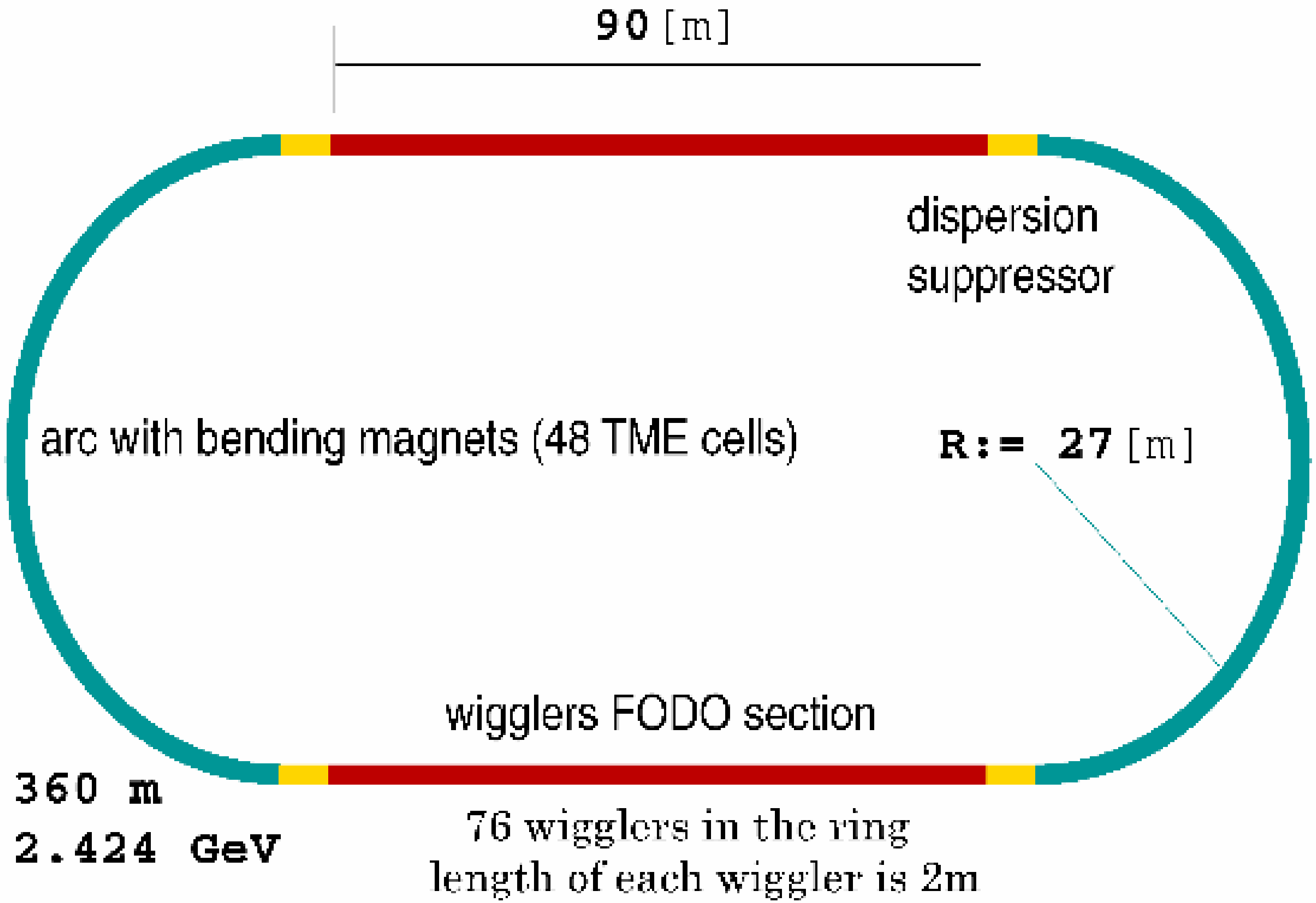


Build wiggler poles symmetric with respect to the beam orbit



M. Preger, P. Raimondi, Wiggle05

layout of the CLIC positron damping ring



C:= 360 m
E:= 2.424 GeV

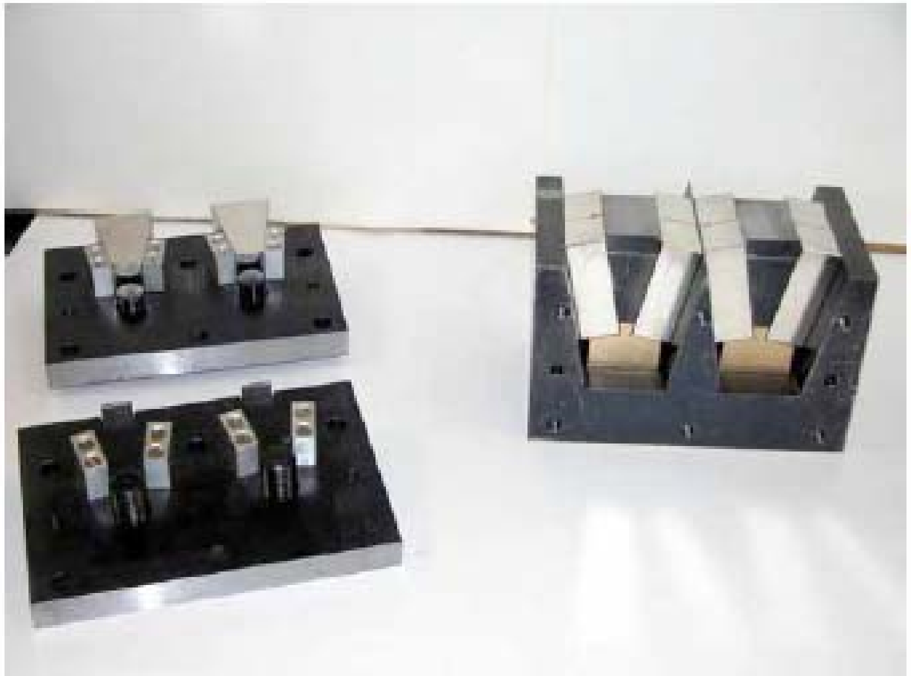
CLIC DR Parameters

Energy (GeV)	2.4
Circumference (m)	360
Bunch number	1554
N particles/bunch	$2.6x10^{-9}$
Damping time (ms)	2.8
Emittance $\gamma\varepsilon_x$ (nm)	550
Emittance $\gamma\varepsilon_x$ (nm)	3.3
Momentum compaction	0.81^{-4}
Energy loss/turn (MeV)	2.1
Energy spread	$1.26x10^{-3}$
Bunch length (mm)	1.55
RF Voltage (MV)	2.39
RF frequency	1875

DR Parameters

	ILC	CLIC
Energy (GeV)	5	2.4
Circumference (m)	6114	360
Bunch number	2820	1554
N particles/bunch	$2x10^{-10}$	$2.6x10^{-9}$
Damping time (ms)	22	2.8
Emittance $\gamma\varepsilon_x$ (nm)	5600	550
Emittance $\gamma\varepsilon_x$ (nm)	20	3.3
Momentum compaction	$1.62x10^{-4}$	0.81^{-4}
Energy loss/turn (MeV)	9.3	2.1
Energy spread	$1.29x10^{-3}$	$1.26x10^{-3}$
Bunch length (mm)	6.0	1.55
RF Voltage (MV)	19.3	2.39
RF frequency (MHz)	650	1875

Permanent magnet wigglers for CLIC



Period	10 cm
Peak field	1.7 T
Wiggler length	160 m
Emittance $\gamma\varepsilon_x$	550 nm
Emittance $\gamma\varepsilon_y$	3.3 nm
Without IBS:	
$\gamma\varepsilon_x$ (w/o IBS)	134 nm

Damping wiggler for the CLIC DR (project)

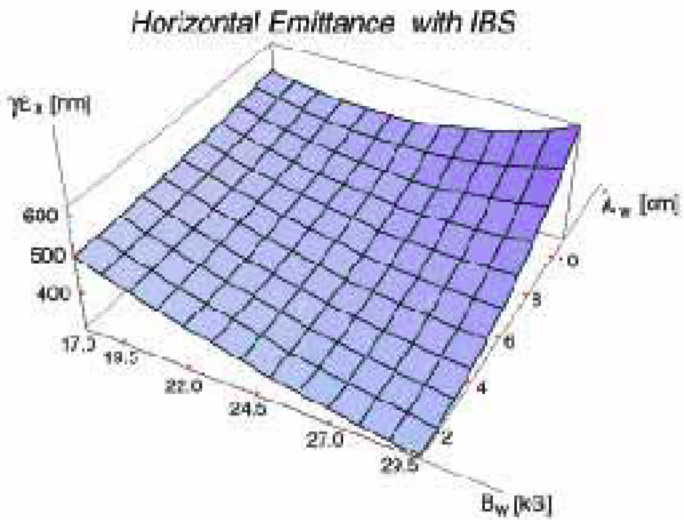
Permanent wiggler:

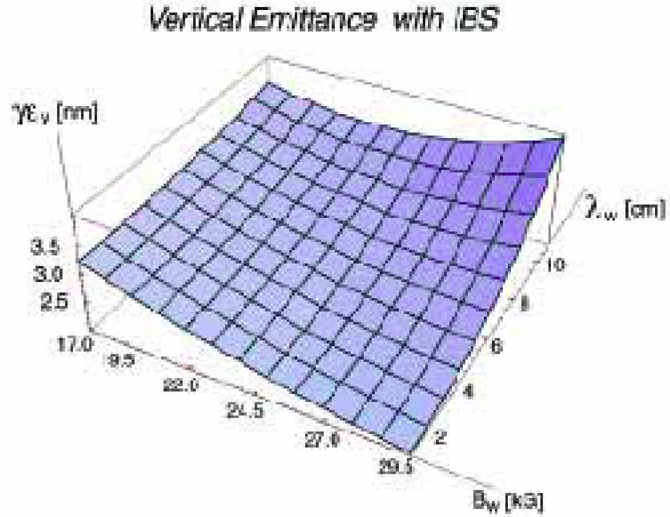
Period:	10 cm
Field amplitude:	1.7 T
Gap:	12 mm
Pole width:	50 mm
Length:	2 m
Field quality @ ±1 cm:	10^{-3}
Total length:	160 m
Total radiation power:	1.7 MV at 1 A

SC wiggler:

❖ Period length	45 mm
❖ Field amplitude	2.5 T
❖ Pole gap	20 mm
❖ Beam aperture	12 mm
❖ Superconductor	Nb_3Sn
❖ Field quality	~10^{-4} at ± 1 cm.

Normalized emittances with IBS of the CLIC DR as a function of wiggler period and wiggler peak field at betatron coupling 0.65%

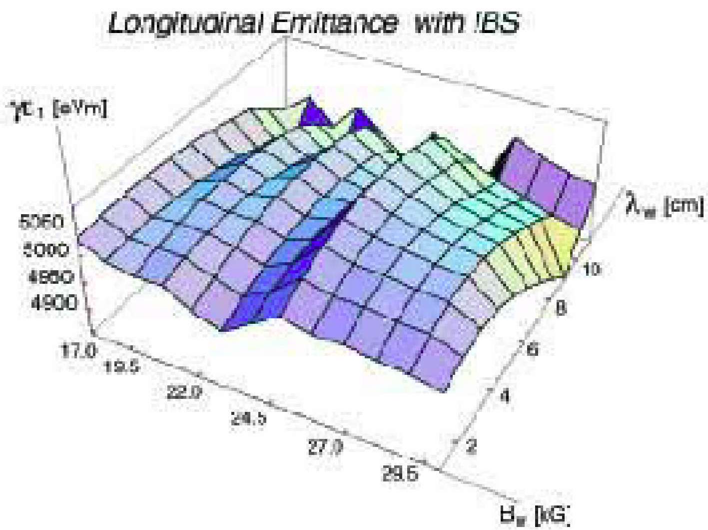




$\gamma\varepsilon_x$ = 400 nm **$\gamma\varepsilon_z$ = 2 nm**

at 2.4 GeV incl. IBS

	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
1.0	494	472	452	432	415	399	382	366	353	341	329	319	309
2.0	495	473	452	433	417	401	385	367	355	344	333	323	314
3.0	496	475	454	436	419	404	389	372	361	350	340	331	324
4.0	498	478	458	440	423	409	395	379	369	360	351	344	338
5.0	502	482	462	445	428	416	404	388	380	373	366	360	357
6.0	505	487	467	452	437	425	414	400	394	389	385	382	382
7.0	510	492	474	460	446	436	427	415	411	409	408	408	412
8.0	515	499	482	469	457	446	440	433	431	430	406	440	449
9.0	522	507	491	481	470	464	461	453	456	462	469	478	494
10.0	534	520	506	497	487	486	486	484	490	500	519	529	549
11.0	542	528	518	508	506	506	506	514	525	537	556	579	607



Maxim Korostelev 16.09.2005 (CLIC meeting)